



COMPARISON OF THREE NON-LINEAR FUNCTIONS FOR DESCRIBING GROWTH CURVES OF FERAL PIGEONS (*COLUMBIA LIVIA*)

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ABSTRACT: This study was undertaken to describe the growth patterns of male and female feral pigeons and determine the most suitable model. Body Weight data from hatch to 28 days of age and 3 nonlinear mathematical functions (Richards, Gompertz, and Logistic) were used to estimate growth patterns of the pigeons. Coefficient of Determination, Mean Square Error and Ease of Convergence were used to determine the best model for describing the growth pattern of male and female squabs. In general, males appeared to be heavier than females though there was no significant ($P > 0.05$) sex effect on body weights at the different ages, an indication that there is no sexual dimorphism in pigeons at the early ages. The Gompertz consistently recorded the highest asymptotic weights (342.54 vs 340.58) for both male and female squabs while the logistic had the least (320.97 vs 317.77). However, the asymptote weights estimated by both Gompertz and Richard models were very close for both males (342.54 vs 342.39) and females (340.58 vs 340.32). This might imply that both models will have almost the same level of accuracy in predicting the weight of squabs. Comparing the models by Akaike's Information Criterion (AIC) values and Mean Square Error (MSE) showed that the Gompertz (7052.8 and 2158.8) had the smallest values for males compared to the Richards (7054.9 and 2161.4) and Logistic (7084.4 and 2234.5) models. A similar trend was observed for females. Though, the R^2 values (> 0.80) showed that all the models adequately described the growth of male and female squabs, the results confirmed that the Gompertz model was more suitable, followed by the Richards and Logistic models based on AIC and MSE.

Keywords: pigeons, models, Gompertz, Richards, Logistic

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1. INTRODUCTION

Pigeons are stocky fast flying birds that mostly feed on the ground, though one group feeds on ripe fruits on tree tops (Stanhope 1978). They are species of medium economic importance though the diversification of poultry products has enhanced its production. They have also been widely used in biomedical research as experimental models. Commercial squab (young pigeons) production has only recently started in Nigeria though it had existed in North America since the early 1990s (Adang *et al.* 2008). Pigeons are monogamous and hatchlings are brooded and fed by their parents until the market age of 4 weeks (Levi 1974). Thus, the population is made up of full sib families. However, prolificacy is low and pair of pigeons can raise about 15 squabs per year.

Nigeria has a total of 190 million pigeons (CBN 1999) and meat from squabs is produced commercially. A priority trait in the poultry industry is growth and the most adequate means of describing growth pattern in poultry is by growth models. This is because, they summarize the information into a few

parameters that can be interpreted biologically (Goliomytis *et al.* 2003). According to Ricklefs (1985), growth models not only explain growth mathematically but also estimate the relationship between feed requirement and live weight which plays a crucial role in animal husbandry. Thus, these models can be used to identify alternative strategies to improve the efficiency of livestock production and to estimate daily nutrient requirements for animals of various ages and genetic groups (Schinckel and De Lange 1996).

Modelling growth of animals is a necessary tool for optimizing management and efficiency of animal production and has many advantages especially for meat producing animals (Schinckel and de Lange 1996). Growth has been described in poultry with several models; Gompertz, Brody, Logistics, bertanlaffy, (three parameter non-linear models), Richards weibull (four parameter non-linear models) and spline regression (linear model). Hruby *et al.* (1996) compared three models (Gompertz, Logistic and linear) and observed that though all the models had similar R^2 values (0.982, 0.981 and 0.939 respectively), the Gompertz described weight of

broilers more precisely up to slaughter age. A similar observation had earlier been made by Kniztova *et al.* (1991). Similarly, Aggrey (2002) compared three non-linear models (Richards, Logistic and Gompertz) and spline linear regression models for describing chicken growth and observed that the spline gave the poorest fit compared to the non-linear models. The non-linear models are able to predict the shape of the growth function more logically than the linear (Hruby *et al.* 1996). There is a dearth of information on the suitable model for describing growth of pigeons. Therefore, this study was designed to determine the best model for describing the growth of squabs raised in a semi-arid area of Nigeria.

2. MATERIALS AND METHODS

The study was carried out in Maiduguri Metropolis, Borno State, Nigeria. Maiduguri, is situated on latitude 11°05' N, longitude 13°09' E and at an altitude of 354 m above sea level. The area falls within the Sahelian region of West Africa, which is noted for great climatic and seasonal variations. It has very short period (3 – 4 months) of rainfall of 645.9 mm/annum with a long dry season of about 8 – 9 months. The ambient temperature could be as low as 20 °C during the dry cold season and as high as 44 °C during the dry hot season. Relative humidity is 45% in August which usually lowers to about 5% in December and January. Day length varies from 11 to 12 hours. Body weights on 192 pigeons of both sexes (102 males and 90 females) from different households keeping pigeons were measured with a digital weighing balance at hatch and three days intervals thereafter till 28 days of age. The pigeons were housed in constructed boxes fixed to high walls and eaves of houses. The collected data was subjected to one way analysis of variance with sex as a fixed factor. The model for the analysis was

$Y_{ij} = U + S_i + e_{ij}$ equation 1
 Where Y_{ij} = individual observation based on the ij classification
 U = overall mean
 S_i = effect of sex
 e_{ij} = random error

2.1 Growth Models

To estimate the body weight at a certain age, two 3-parameter and a 4-parameter nonlinear growth models were fitted to the squabs body weight data.

Table 1. Models used for describing growth of pigeons

Model name	Equation
Gompertz	$Y = a \cdot \exp(-b \cdot \exp(-k \cdot \text{age}))$
Logistic	$Y = a \cdot (1 + b \cdot \exp(-k \cdot \text{age}))^{-1}$
Richard	$Y = a \cdot (1 \pm b \cdot \exp^{-k \cdot \text{age}})^{1/(1-m)}$

From the equations in Table 1, Y is the body weight (g) of birds at x days of age; a, b and k are model parameters where a is asymptotic weight when time goes to infinity, when adult weight is not reached, the parameter reflects an estimation of the weight at the last weighing (Freitas 2005); b is a scaling parameter (constant of integration), which is related with initial values of Y, and k is relative growth rate. m: the shape parameter connecting inflection point in Richards’s growth function, where the predictable growth rate varies from an increasing to a decreasing function for body weight (Bilgin *et al.* 2004). The Gompertz and Logistic models have 3 parameters in their equations, with fixed inflection points. The 4-parameter Richards function was developed as an advancement of the logistic and the Gompertz functions and has a flexible point of inflection.

2.2 Statistics and Model Comparison

Curve parameters were obtained with the Levenberg-Marquardt iteration method using the nonlinear regression procedure of Statistix 9.0 software. Goodness of fit for the models was determined by the coefficient of determination (R^2) and the models were compared by using Mean Square Error and Akaike’s Information Criterion (AIC; Akaike, 1973):

$AIC = -2Lm + 2m$ equation 2
 where Lm is the maximized log-likelihood and m is the number of parameters in the model. The AIC takes into account both the statistical goodness of fit and the number of parameters that need to be estimated to achieve this particular degree of fit, by imposing a penalty for increasing the number of parameters. Lower values of the AIC indicate the preferred model; that is, the one with the fewest parameters that still provides an adequate fit to the data (Köhn *et al.* 2007).

3. RESULTS AND DISCUSSION

Means and standard error of body weights of male and female pigeons at the different ages are presented on Table 1. In general, the males appeared to be heavier than females but there was no significant sex effect on body weights at the different ages. This may indicate that there is no sexual dimorphism in pigeons at the early ages. This agrees with the report of Mignon-Grasteau *et al.* (2000) but contradicts those of Ibrahim and Akut (2007) who reported significantly heavier males than females at all ages. However, the authors reported an average weight of 12.81 g at hatch which was within the range of 12.73 to 13.51 g reported in this study. As expected with time series data, there was a general increase of standard error with age for both sexes. A similar observation was earlier made by Nahashon *et al.* (2006).

The Gompertz, Logistics and Richards models were used to assess growth pattern of young pigeons. The fitted parameters and goodness of fit criteria for the 3

nonlinear growth models for male and female squabs are presented in Table 2. The Gompertz consistently recorded the highest asymptotic weights (342.54 vs 340.58 g) for both male and female squabs while the logistic had the least (320.97 vs 317.77 g). Though, the asymptotic weights of male and female squabs did not vary very much, those of males appeared to be higher for all the models. Similarly, the asymptote weights estimated by both Gompertz and Richards models were very close for both males (342.54 vs 342.39 g) and females (340.58 vs 340.32 g). In order words, asymptotic body weights predicted by the Richards model for both males and females were comparable with the predictions from the Gompertz model. This might imply that both models will have almost the same level of accuracy in predicting the weight of squabs. Gao *et al.* (2016) reported higher asymptote weights (507.72 and 494.41g) as predicted by the Gompertz and Logistic models, respectively in pigeons. Xiang and Wang (2000) also reported higher asymptote weight (514.9 g) in pigeons. The higher weight obtained by the authors could be due to the fact that the birds in their studies were kept till 35 days of age while this study was terminated at 28 days.

The values estimated for parameter k (maturity index) were higher in logistic (0.22), than Gompertz (0.13) and Richards (0.13) for males and females. There was no difference between sexes, stressing the influence of initial (hatch) weight on mature weight in pigeons. In addition, it may further buttress the point that sexual dimorphism might not exist among pigeon squabs. Similarly, there was not much difference in the value of the shape parameter m estimated by the Richards model for male and female. The values tended towards 0 indicating that the shape of the pigeon growth curve is the Gompertz. Goliomytis *et al.* (2003) made similar observation in broiler chickens.

Comparison of the models based on their behaviour (Figures 1 and 2) showed that they all gave a suitable fit to the growth data. In order words, the predicted growth curves did not deviate substantially from the actual live body weights at the different ages. Thus, the shape of the predicted growth curves was typically sigmoid for both male and female squabs. However, the growth trajectory predicted by the Richards and Gompertz were similar for both male and female squabs except for the male at 18 days of age where the trajectory predicted by the Richards model deviated slightly from the Gompertz model. Galeano-Vasco *et al.* (2014) also made similar observation in laying chickens.

The R^2 values (>0.90) also showed that the models (except Logistic for males; 0.83) adequately described the growth of male and female squabs. The Richards model had the highest (0.96) R^2 for male squabs and the Logistic the lowest (0.83). The R^2 was similar for

the Richards and Gompertz models (0.93) for females and the Logistic slightly lower (0.92). Theoretically, the four parameter Richards model is expected to give a higher R^2 than the three parameter Gompertz and Logistic models. However, because the growth trajectory predicted by the Richards model is close to the Gompertz model, the R^2 were similar. For male squabs, the Richards model had higher R^2 (0.96) than the other models (0.92 and 0.83 for the Gompertz and Logistic, respectively).

Comparing the models by Akaike's Information Criterion (AIC) values and Mean Square Error (MSE) showed that the Gompertz (7052.8 and 2158.8) had the smallest values for males compared to the Richards (7054.9 and 2161.4) and Logistic (7084.4 and 2234.5) models. A similar trend was observed for the females. This indicates that the Gompertz is the best model for predicting growth of squabs. Gao *et al.* (2016) also reported good fitting for pigeons growth data with the Gompertz and Logistic models ($R^2 > 0.99$) with the Gompertz having the highest as observed in this study. Xiang and Wang (2000) also indicated that Gompertz function had higher R^2 than the other functions in pigeon weight data fitting. Galeano-Vasco *et al.* (2014) in a study with laying compared four models using the AIC and concluded that the Gompertz gave the best fit followed by the Richards. The AIC is useful for comparing models with different numbers of parameters and is more advantageous than the R^2 , which increases with increasing numbers of parameters in the models and thus is not useful for the comparison of models with different numbers of parameters. The comparison of different models with this method determines which model is more likely to be correct and accounts for differences in the number of degrees of freedom. Thus, the model with the smallest AIC value is the best for fitting pigeon's body weight data (Köhn *et al.* 2007). Mohammed (2015) also reported a lower MSE for the Gompertz when the author compared the Gompertz, Logistics and Von Bertalanffy Models for describing growth of broilers.

The Gompertz converged earlier than the other two models for both male and female squabs. The ease of convergence for both male and female respectively for the Gompertz, Logistic and Richards models were 10 vs 9, 12 vs 12 and 100 vs 100, respectively. Cetin *et al.* (2007) in a study with partridges also observed that the Richards gave more iterations than the Gompertz and Logistic models.

The coefficients of correlation among parameters of the different models are presented in Table 3. The correlations between b and k , b and m and, k and m were high and positive while a and b , and a and m were negative for all models. The correlations between parameters a and k , were generally high and negative for all models. The correlation among

parameters indicates that heavier birds are less precocious due to the antagonism between parameters a and k . There is a pronounced correlation among the growth parameters estimated from growth models (Mignon-Grasteau *et al.*, 1999). A similar observation was also made by Mohammed (2015).

4. CONCLUSION

1. All the models (Gompertz, Logistic and Richards) can be used to describe growth of

squabs but the Gompertz and Richards gave a better fit to the data.

2. The Gompertz may be preferred because of ease of convergence and fewer parameters while when a four-parameter model with flexible inflection point is desired, the Richards may be used.
3. The need for sex separated feeding as has been advocated for some intensively reared poultry species may not arise since there is no evidence of sexual dimorphism among pigeons.

Table 1. Means and SE of bodyweights (g) of pigeons as influenced by sex

Age (days)	Overall	Male	Female
0	13.65±0.34	13.51±0.35	12.73±0.77
3	58.70±1.59	59.80±1.54	56.32±3.31
7	118.91±2.87	119.96±2.84	110.05±6.10
10	179.37±4.05	178.90±4.05	169.14±8.73
14	230.62±5.00	230.11±5.01	215.27±10.79
18	267.15±5.51	264.47±5.57	260.73±11.98
21	295.94±5.39	292.56±5.45	292.36±11.74
24	313.79±5.39	312.12±5.41	307.55±11.66
28	324.68±5.22	325.14±5.19	313.45±11.18

Means within rows without superscripts are not significantly ($P>0.05$) different.

Table 2. Parameter estimates and goodness of fit criteria for the different models for male and female squabs

Parameters	Male			Female		
	Gompertz	Logistics	Richards	Gompertz	Logistics	Richards
A	342.54	320.97	342.39	340.58	317.77	340.32
B	1	2.16	4.47	1.04	2.23	4.02
K	0.13	0.22	0.13	0.13	0.22	0.13
M			0.004			0.006
R ²	0.92	0.83	0.96	0.93	0.92	0.93
MSE	2158.8	2234.5	2161.4	806.75	858.39	811.07
AIC	7052.8	7084.4	7054.9	1330.4	1342	1332.5
Convergence criterion	10	12	100	9	12	100

MSE = Mean Square Error

AIC = Akaike Information Criterion

Table 3. Correlation coefficients of the model parameters

Parameters	Male			Female		
	Gompertz	Logistics	Richards	Gompertz	Logistics	Richards
Rab	-0.47	-0.35	-0.81	-0.49	-0.37	-0.81
Rak	-0.86	-0.71	-0.93	-0.87	-0.73	-0.93
Ram			-0.81			-0.81
Rbk	0.78	0.84	0.9	0.79	0.84	0.95
Rbm			1			1
Rkm			0.95			0.95

r = correlation

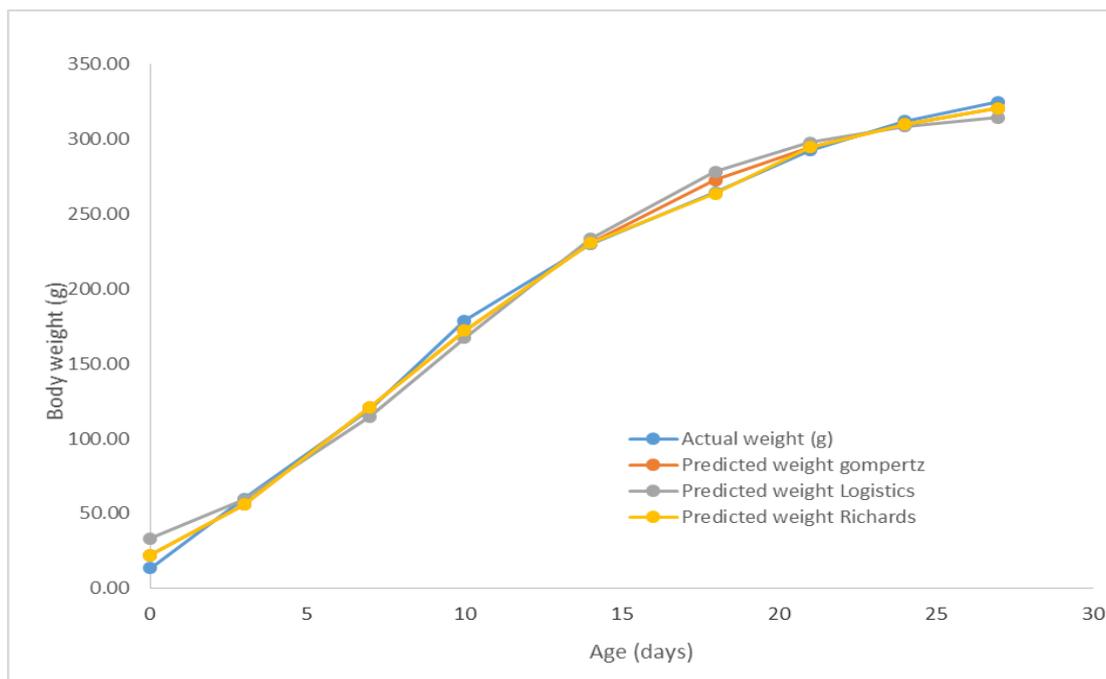


Figure 1. Actual and predicted weight of male squabs

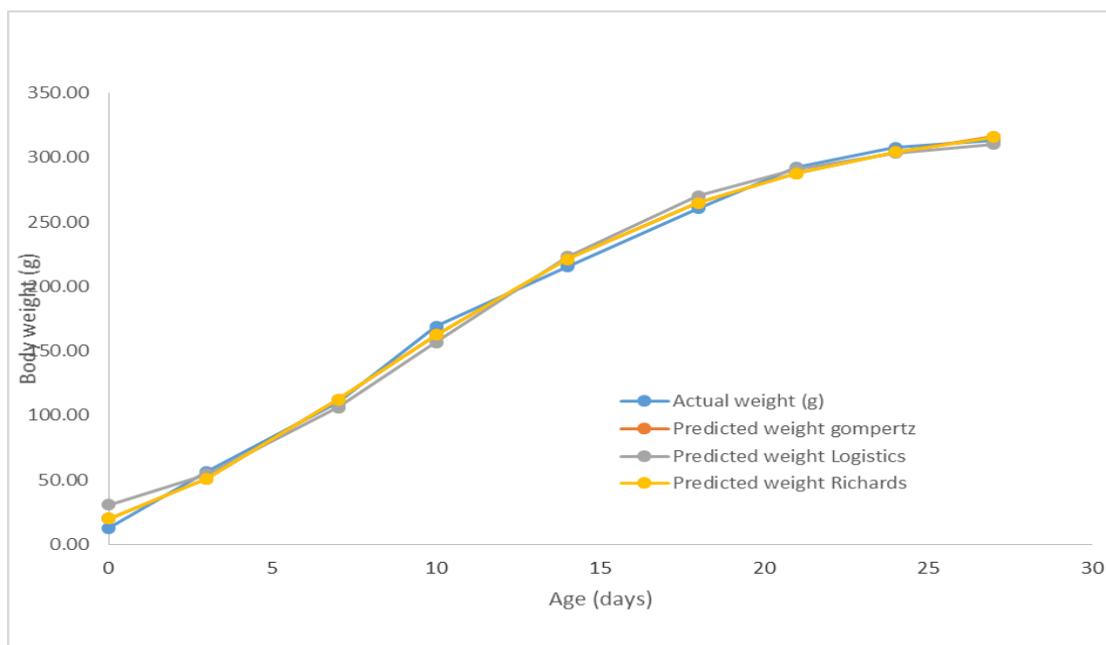


Figure 2. Actual and predicted weight of female squabs

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